

BIOLOGICAL CRITERIA
Technical Guidance for Streams and Small Rivers

CHAPTER 5: Evaluating Environmental Effects	77
Water Quality	77
Habitat Structure	81
Habitat Quality and Biological Condition	82
Development of Habitat Assessment Approach	83
Flow Regime	85
Energy Source	88
Biotic Interactions	90
Cumulative Impacts	90
Suggested Readings	91

CHAPTER 5.

Evaluating Environmental Effects

Should a biological survey reveal a significant departure from reference conditions or criteria, the next step is to seek diagnostic information leading to remedial action. This action entails the investigation of an array of physical, chemical, and biological factors to determine the likely source of degradation in the water resource.

Five major environmental factors affect and determine water resource integrity (Karr and Dudley, 1981; Karr et al. 1986). These factors are water quality, habitat structure, flow regime, energy source, and biotic interactions. Monitoring programs must integrate, measure, and evaluate the influences of these factors (Fig. 5-1). A comprehensive discussion of all five and the enormous variety of human actions that alter them is beyond the scope of this document. We can, however, present a conceptual sketch of each one and how it influences the integrity of the water resource. Several considerations are involved in evaluating these complex factors.

Human actions often alter one or more of those factors and thus alter the resident biota. Alterations may be obvious, such as the extinction of species or the introduction of exotics, or they may be more subtle, such as altered survival rates, reproductive success, or predation intensity. Protection or restoration of biotic integrity requires identification of the processes that have been altered by human actions. Careful evaluation of the conditions in a watershed can play a critical role in identifying the potential causes of degradation. That identification process is essential to develop the most cost-effective approaches to improving the quality of water resources.

Water Quality

The physical and chemical attributes of water are critical components of the quality of a water resource. Because the earliest water resource legislation (e.g., the Refuse Act of 1899) dealt with disease and oil pollution in navigable waters, emphasis has traditionally been on the physical and chemical properties of water. Physical and chemical attributes of special concern include but are not limited to temperature, dissolved oxygen, pH, hardness, turbidity, concentrations of soluble and insoluble organics and inorganics, alkalinity, nutrients, heavy metals, and an array of toxic substances. These substances may have simple chemical properties, or their

Purpose:

To provide managers with an understanding of the factors that affect and determine water resource integrity.

**ECOLOGICAL
IMPACT OF
HUMAN-INDUCED
ALTERATIONS**

1. Energy Source

Type, amount, and particle size of organic material entering a stream from the riparian zone versus primary production in the stream

Seasonal pattern of available energy

→ *Decreased coarse particulate organic matter*
Increased fine particulate organic matter
Increased algal production

2. Water Quality

Temperature

Turbidity

Dissolved oxygen

Nutrients (primarily nitrogen and phosphorus)

Organic and inorganic chemicals, natural and synthetic

Heavy metals and toxic substances

pH

→ *Expanded temperature extremes*
Increased turbidity
Altered diurnal cycle of dissolved oxygen
Increased nutrients (especially soluble nitrogen and phosphorus)
Increased suspended solids

3. Habitat Structure and Quality

Substrate type and quantity

Water depth and current velocity

Spawning, nursery, and hiding places

Diversity (pools, riffles, woody debris)

→ *Decreased stability of substrate and banks due to erosion and sedimentation*
More uniform water depth
Reduced habitat heterogeneity
Decreased channel sinuosity
Reduced habitat area due to shortened channel
Decreased instream cover and riparian vegetation

4. Flow Regime

Water volume

Temporal distribution of floods and low flows

Flow regulation

→ *Altered flow extremes (both magnitude and frequency of high and low flows)*
Increased maximum flow velocity
Decreased minimum flow velocity
Reduced diversity of microhabitat velocities
Fewer protected sites

5. Biotic Interactions

Competition

Predation

Disease

Parasitism

→ *Increased frequency of diseased fish*
Altered primary and secondary production
Altered trophic structure
Altered decomposition rates and timing
Disruption of seasonal rhythms
Shifts in species composition and relative abundance
Shifts in invertebrate functional groups (increased scrapers and decreased shredders)
Shifts in trophic guilds (increased omnivores and decreased piscivores)
Increased frequency of fish hybridization

Figure 5-1.—Five major classes of environmental factors that affect aquatic biota in lotic systems. Right column lists selected expected results of anthropogenic perturbation (Karr et al. 1986).

dynamics may be complex and changing, depending on other constituents in a particular situation including the geological strata, soils, and land use in the region. The number of elements and compounds that influence water quality is very large without human influences; with them, the complexity of the problem is even greater. The human effects on biological processes may be direct (i.e., they may cause mortality), or they may shift the balance among species as a result of subtle effects, such as reduced reproductive rates or changing competitive ability. Aquatic life use designations provide protection at various levels from the multitude of anthropogenic effects.

The EPA encourages states to fully integrate biological surveys, whole-effluent and ambient toxicity testing, and chemical-specific analyses to assess attainment or nonattainment of designated aquatic life uses in state water quality standards (U.S. Environ. Prot. Agency, 1991c). Ohio EPA used numeric biological criteria within an existing framework of tiered aquatic life uses to establish attainable, baseline expectations on a regional basis (Yoder, 1991). Use attainment status in the Ohio water quality standards results in a classification of "full attainment," if all applicable numeric biocriteria are met; "partial attainment," if at least one aquatic assemblage exhibits nonattainment but no lower than a "fair" narrative rating; and "nonattainment," if none of the applicable biocriteria are met, or if one assemblage reflects a "poor" or "very poor" narrative rating.

North Carolina's Department of Environment, Health, and Natural Resources has used in-stream biota to assess water quality since the mid-1970s (Overton, 1991), and the water quality regulations in the North Carolina code have been revised to take biological impairment into account. In addition, when fiscal realities in North Carolina required a more efficient water quality program, all NPDES permits within a given river basin were scheduled to be issued within the same year (Overton, 1991). The same strategy makes biological assessment more efficient because the department can focus the assessment on specific river basins coincident with the renewal permits. Other states may have to consider similar strategies to conserve resources.

The Maryland Department of the Environment, Water Quality Monitoring Division, uses biological assessment as part of a statewide water quality monitoring network (Primrose et al. 1991). Using biological assessment, Maryland has been able to differentiate among various degrees of impairment and unimpairment, and to distinguish particular water quality impacts.

The Arkansas Department of Pollution Control and Ecology developed a bioassessment technique in the mid-1980s to assess the impact on receiving waters of discharges exceeding water quality-based limits (Shackleford, 1988). Using its bioassessment approach as a screening tool, Arkansas follows a formal decision tree for assessing compliance with established water quality limits (Fig. 5-2). The initial bioassessment screen may result in the application of other biological, toxicological, or chemical methods. After completion of screening, an on-site decision can be made for subsequent action. In situations where "no impairment" or "minimal impairment" classifications are obtained, field efforts are reduced in frequency or intensity until further information indicates a problem. Streams classified as "substantially" or "excessively" impaired trigger additional

The EPA encourages states to fully integrate biological surveys, whole-effluent and ambient toxicity testing, and chemical-specific analyses to assess attainment or nonattainment of designated aquatic life uses in state water quality standards.

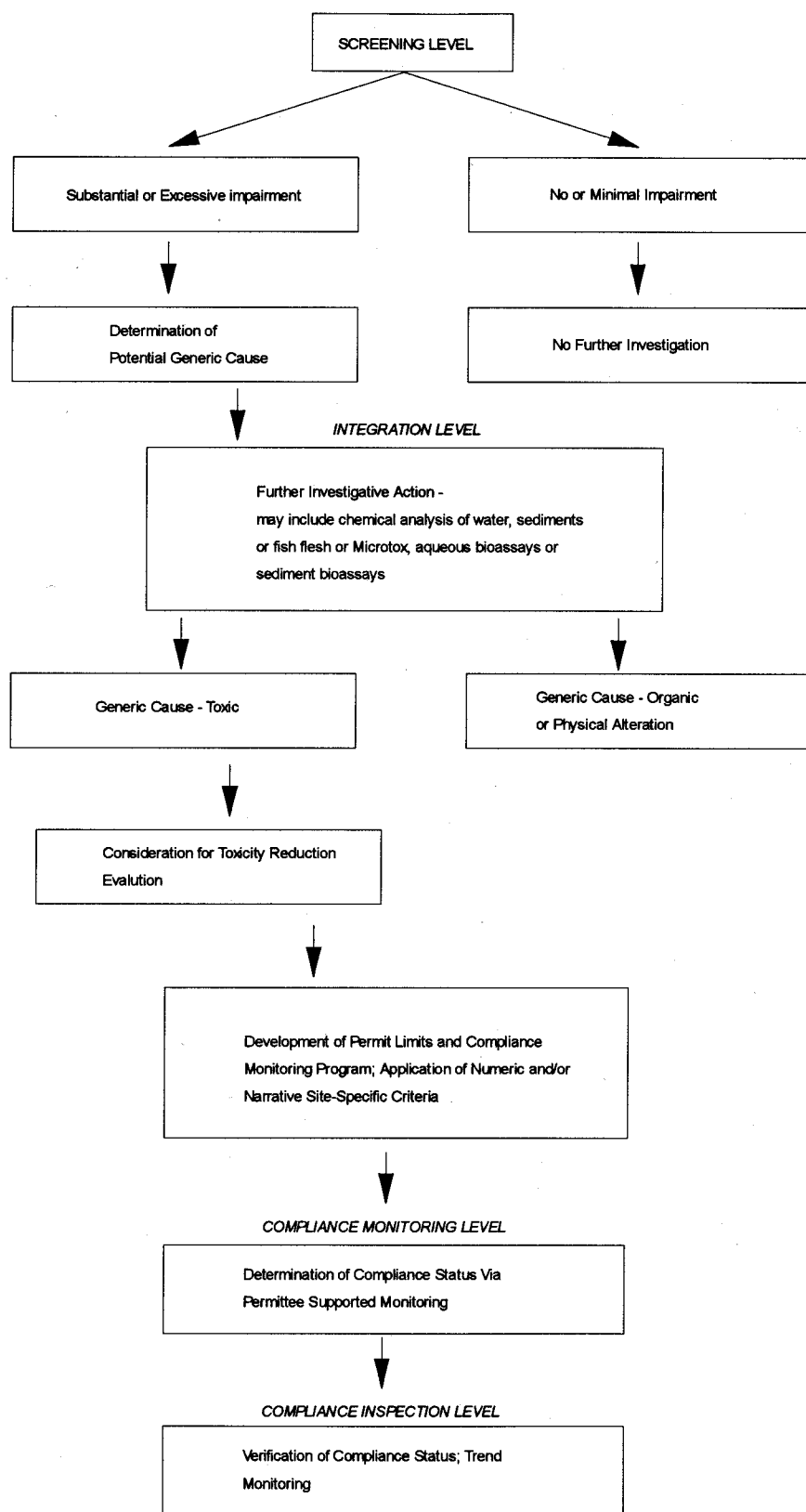


Figure 5-2.—Decision matrix for application of rapid bioassessments in Arkansas for permitted point source discharges (Shackleford, 1988).

investigative steps that employ an integration of methods (Shackleford, 1988).

The definitive evaluation of water quality impacts often requires expensive laboratory analyses. However, careful review of conditions in the watershed can provide early warning signals about the potential for water resource degradation. For example, the presence of industrial, domestic, and agricultural sources of chemical contaminants may be indicated by odors, froth, or colors in the water. These conditions should be noted during field surveys for their potential diagnostic value.

Habitat Structure

The physical structure of stream environments is critical to the ecological health or integrity of lotic water resources. Attributes of significance to organisms in streams are channel morphology including width, depth, and sinuosity; floodplain shape and size; channel gradient; in-stream cover such as presence of boulders and woody debris; substrate type and the diversity of substrates within a stream reach; riparian vegetation and the canopy cover that it provides; and bank stability.

Channel morphology in natural watersheds is typically meandering with substrate diversity created by varying velocities along and across the channel. As a result, substrates are sorted to form pools and riffles that create horizontal variation in the physical environment. If a channel has been artificially straightened and dredged (channelized), temporal recovery will recreate substrate diversity through vertical and lateral meandering processes (Hupp, 1992; Hupp and Simon, 1986). Because no stream channel is stable, a temporal dimension of diversity also exists. These physical attributes are closely tied to other environmental conditions and impairments (Table 5-1).

The influence of habitat structure spans the range from regional geography to the pattern of interstitial spaces between rocks in the river substrate. Habitat structure on all scales is critical to the biology of most stream organisms, and subtle or massive habitat alteration on any scale may influence the quality of the water resource.

The influence of habitat structure on the aquatic community causes natural variability even in undisturbed communities. Understanding the relationship of expected trends in biological condition as a result of changes in habitat structure is an important feature of biological assessments. Ohio EPA found that their measurement of habitat quality, the Qualitative Habitat Evaluation Index (QHEI), was significantly correlated with the Index of Biotic Integrity (IBI) in Ohio streams (Fig. 5-3) with $r = 0.47$ (Rankin, 1991) on a broad scale over the state. Rankin also found that stream habitat quality and land use at various geographic scales are important influences on fish assemblages and that relatively intact stream habitat throughout the drainage can compensate for short stretches of poor habitat. In contrast, however, habitat-sensitive species may be reduced or destroyed in stream basins with extensive degraded conditions, even if short stretches of good habitat exist. The Maryland Department of the Environment, using the relationship between habitat structure and biological condition, demonstrated effects from various influences (Fig. 5-4) including agricultural runoff, treatment plant effluent, channelization, and landfill operations (Primrose et al. 1991).

Careful review of conditions in the watershed can provide early warning signals about the potential for water resource degradation.

An assessment of habitat structure is critical to any evaluation of ecological integrity. Habitat assessment provides information on habitat quality; it also identifies obvious constraints on the site's potential to achieve attainment, assists in the selection of appropriate sampling stations, and provides basic information for interpreting biosurvey results.

Table 5-1.— Parameters that may be useful in evaluating environmental conditions and their relationship to geographic scales and the environmental factors influenced by human actions.

CATEGORY BY GEOGRAPHIC SCALE	PARAMETER	ENVIRONMENTAL FACTORS ^{i,j}
1. Watershed	Land use ^f Flow stability ^f	Flow regime Physical habitat
2. Riparian and bank structure	Upper bank stability ^{a,f,h} Bank vegetative stability ^{a,f,h} Woody riparian vegetation ^h — species identity — number of species Grazing or other disruptive pressures ^{a,f} Streamside cover (% vegetation) ^{a,f} Riparian vegetative zone width ^{a,f} Streambank erosion ^f	Flow regime Energy base Physical habitat
3. Channel morphology	Channel alteration ^{a,d,f} Bottom scouring ^a Deposition ^a Pool/riffle, run/bend ratio ^{a,c} Lower bank channel capacity ^a Channel sinuosity ^{a,f,h} Channel gradient ^{f,h} Bank form/bend morphology ^h	Flow regime Energy base Biotic interactions Water quality Physical habitat
4. In-stream	Substrate composition/size; % rubble, gravel, submerged logs, undercut banks, or other stable habitat ^{a,c,d,e,f} % pools ^f Pool substrate characterization ^a Pool variability ^a % embeddedness of gravel, cobble, and boulder particles by fine sediment; sedimentation ^{a,c,f} Rate of sedimentation Flow rate ^{a,d} Velocity/depth ^{a,d,e} Canopy cover (shading) ^{a,f} Stream surface shading (vegetation, cliffs, mountains, undercut banks, logs) ^{b,d,f} Stream width ^{c,h} Water temperature ^c	Flow regime Energy base Biotic interactions Water quality Physical habitat

REFERENCES:

^aPlafkin et al. 1989

^bPlatts et al. 1987

^cPlatts et al. 1983; Armour et al. 1983

^dRankin, 1991

^eGorman, 1988

^fOsborne et al. 1991

^gBarton et al. 1985

^hHupp and Simon, 1986; 1991

ⁱKarr and Dionne, 1991

^jKarr, 1991

Habitat Quality and Biological Condition

The variability of environmental conditions directly affects patterns of life, population, and the micro- and macrogeographic distribution of organisms (Cooper, 1984; Price, 1975; Smith, 1974). An assessment of habitat structure is therefore critical to any evaluation of ecological integrity (Karr et al. 1986; Plafkin et al. 1989). Habitat assessment provides information on habitat quality; it also identifies obvious constraints on the site's potential to achieve attainment, assists in the selection of appropriate sampling sta-

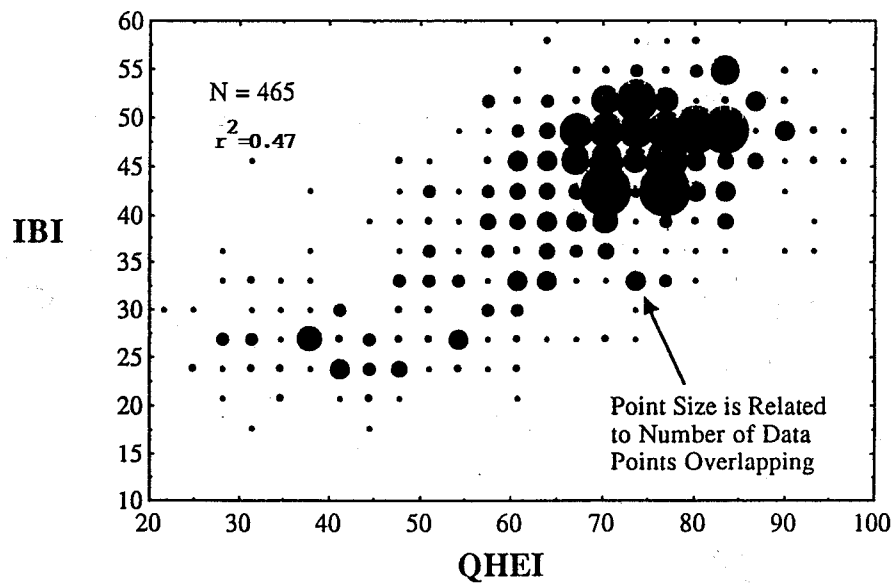


Figure 5-3.—Qualitative Habitat Evaluation Index (QHEI) versus the Index of Biotic Integrity (IBI) for 465 relatively unimpacted and habitat modified Ohio stream sites (Rankin, 1991).

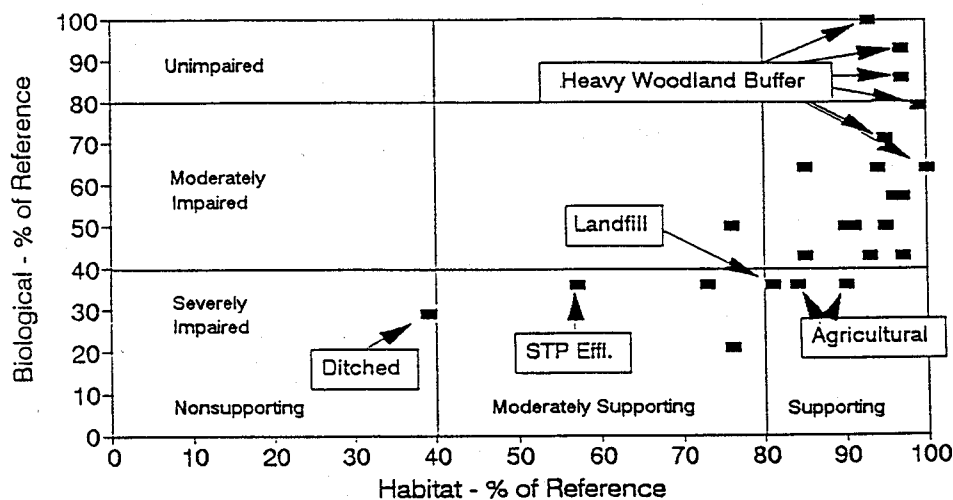


Figure 5-4.—Choptank and Chester rivers tributaries (Primrose et al. 1991).

tions, and provides basic information for interpreting biosurvey results (Atkinson, 1985; Osborne et al. 1991). A carefully conducted habitat evaluation is essential for distinguishing cause and effect elements from among the five environmental factors influenced by human activity.

Development of a Habitat Assessment Approach

The development of a stream habitat assessment approach follows a logical sequence beginning with the characterization of the waterbody. Only similar aquatic systems may be compared; habitat structural parameters applicable to one part of the country may not be applicable in another. For instance, the extent of canopy cover differs between forested mountain streams and open prairie streams found in the southwest. Thus, the absence of canopy cover is a more important habitat influence in a forested

Only similar aquatic systems may be compared; habitat structural parameters applicable to one part of the country may not be applicable in another.

The development of a stream habitat assessment follows a logical sequence.

Waterbody Characteristics

Selection of the taxa
(Benthic Macro-invertebrates, Fish)

Influential Habitat
Variables
(Flow, Shade, Substrate,
Buffer Zone)

Judgment Criteria
(Optimal, Suboptimal,
Marginal, Poor)

Gradient is perhaps the most influential factor for segregating a lotic waterbody because it is related to topography and landform, geological formations, and elevation, which in turn influence vegetation patterns.

stream than in open streams (Barbour and Stribling, 1991). Another consideration would be broad physiographic characteristics, for example, elevation, general topography and gradient, and predominant soil types. Finally, the biogeographic distribution of species and assemblages of organisms varies regionally.

Selection of the taxa, that is, the biological community to be studied, is the important next step. Ideally, this selection is based on the best approach to a comprehensive water resource assessment. However, the availability of resources and the training of available staff will have significant influence.

The selection of one or more assemblages is important for determining which habitat variables are most influential for community development. For each parameter, the range of conditions to be expected is determined and divided into scoring categories. These scoring categories (optimal, suboptimal, marginal, and poor) form the basis of criteria that allow habitats to be judged during on-site evaluation. An important call must then be made. If habitat structure is degraded relative to the expectations provided by the appropriate reference condition, some inference must be drawn about the nature and cause of the difference. If the study site is degraded relative to the reference, then habitat structure has been identified as a potential cause of reduced biotic condition. If habitat structural differences result from the natural landscape rather than human interference, then the possibility that an inappropriate reference condition was used must be considered.

The habitat assessment approach outlined here (following Barbour and Stribling, 1991; Plafkin et al. 1989) is applicable to wadable streams and rivers. Because fish and benthic macroinvertebrates are the focal points of these recommended bioassessment procedures, habitat structural parameters were chosen that influence the development of these communities. Although streams across the country exhibit a wide range of variability, some generalizations can be made. Gradient is perhaps the most influential factor for distinguishing lotic waterbodies because it is related to topography and landform, geological formations, and elevation, which in turn influence vegetation patterns. Four generic stream categories related to gradient can be identified: mountain, piedmont, valley plains, and coastal plains. Several habitat attributes serve as a framework for assessing habitat quality:

- Substrate variety/in-stream cover
- Bottom substrate characterization/embeddedness
- Flow or velocity/depth
- Canopy cover (shading)
- Channel alteration
- Bottom scouring and deposition
- Pool to riffle and run to bend ratios, channel sinuosity
- Lower bank channel capacity
- Upper bank stability
- Bank vegetative stability (grazing or other disruptive pressure)
- Streamside cover
- Riparian vegetative zone width

While the investigator is on-site, the quality of each parameter can be assessed. First, numeric value from a scale based on a gradient of conditions is assigned to assess the quality of each parameter. Then, a composite of information from each parameter is compared to a reference condition. Such a quantified assessment of habitat structure provides a more meaningful interpretation of biological condition. Habitat assessment incorporates information on stream segments or reaches. However, a linear relationship between site-specific quality of habitat and community performance may not exist to the point that habitat structural condition can be used to "predict" biological performance with accuracy.

If habitat degradation has occurred, mitigation or improvement of the habitat through stream restoration activities should be evaluated. Implementation of water quality improvements can be independent of habitat quality, but judgment of the improvement in biological integrity cannot.

Flow Regime

Fluctuating water levels are an integral part of the stream ecosystem, and the biota are dependent on seasonal flow variation. High flow events are especially important in maintaining the habitat complexity of pools, riffles, clean substrates, and bars (Hill et al. 1991). Aquatic organisms have evolved to compensate for changing flow regimes, even periodic catastrophic flow conditions. High water periods are determined by the frequency, occurrence, and type of precipitation event as well as antecedent conditions such as soil moisture, time since last rain, and amount and type of soil cover. Dewatering the channel for major periods as a result of human actions is clearly a degradation of the water resource, but more subtle changes in the volume and periods of flow may have equally devastating effects on the resident biota.

Jones and Clark (1987) discuss the effects of urbanization on the fundamental hydrology of watersheds and the natural flow regime. Increases in impervious surface area (e.g., roads, parking lots) result in a substantial increase in the proportion of rainfall that is rapidly discharged from the watershed as direct runoff and streamflow. Such runoff increases the volume of flood flows and instances of channel instability. Leonard and Orth (1986) developed a cultural pollution index to evaluate the health of the fish community subject to the effects of road density, population encroachment, mining, and organic pollution. These effects have substantial influence on flow regime. Steedman (1988) also evaluated the condition of fish communities in heavily urbanized areas of Ontario. He found that certain attributes that are relatively sensitive to urbanization effects can serve as pertinent response signatures.

Ohio EPA found that the presence or absence of channelization influenced the relationship between the quality of habitat structure and the condition of the fish community (Ohio Environ. Prot. Agency, 1990). In the absence of channelization, for example, Twin Creek and Kokosing River (Fig. 5-5) had high IBI values, even in the presence of sporadic degraded habitat. In these instances, the relatively good habitat quality throughout the watershed supported the fish community in short reaches of degraded, habitat (Rankin, 1991). In channelized lotic systems, for example, Tiffin River and Little Auglaize River (Fig. 5-5), the best habitats were de-

Implementation of water quality improvements can be independent of habitat quality, but judgment of the improvement in biological integrity cannot.

Fluctuating water levels are an integral part of the stream ecosystem, and the biota are dependent on seasonal flow variation.

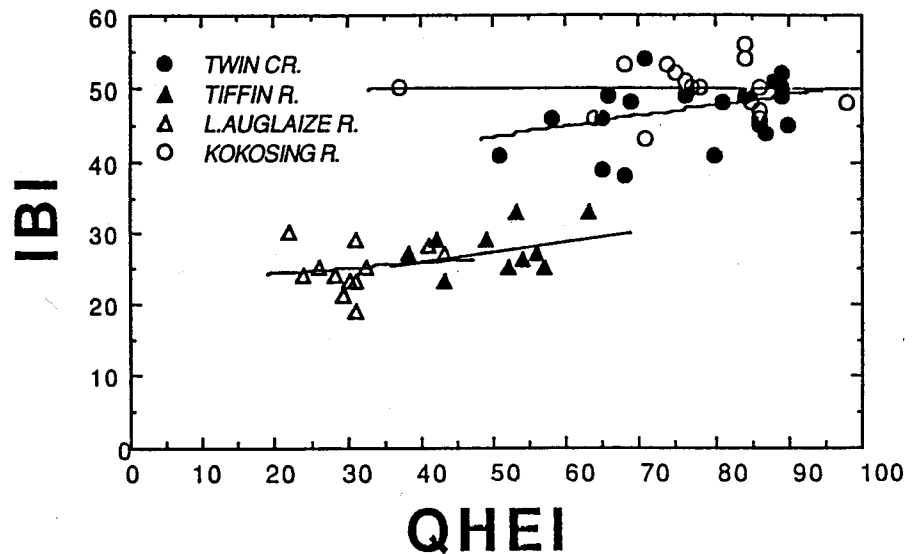


Figure 5-5.—Relationship of the Index of Biotic Integrity (IBI) to changes in the quality of habitat structure through the Qualitative Habitat Evaluation Index (QHEI) in channelized (triangles) and unchannelized (circles) (Ohio Environ. Prot. Agency, 1990).

graded and IBI scores remained essentially unchanged as the habitat was degraded further. The quality of habitat structure and the flow regime are intricately associated. In areas of extensive channelization, communities may consist only of generalists and opportunists able to withstand harsh flow conditions directly, or the secondary effects of those flow conditions (e.g., reduced abundance of food or presence of habitat refuges).

■ **Effects of Channelization.** Unchannelized or otherwise unmodified streams have normal, low-level, and mostly consistent rates of sediment deposition on the bed and low, convex banks. The channel usually has some degree of meandering, and the banks lose very little mass during either low or high flows.

Efforts to control flooding and to drain wetlands often involve channelization of streams to provide more rapid removal of water. Unfortunately, these activities create unstable channels with higher gradients and without meanders. Hydrogeomorphic processes tend to restore the dynamic stability of these systems over time (Hupp and Simon, 1991). The stream continuum hypothesis (Vannote et al. 1980) depicts the stream as an upstream-downstream gradient of gradually changing physical conditions and associated adjustments in functional attributes of the biota.

Biological processes in downstream areas are linked to those in upstream areas by the flow of water, nutrients, and organic materials. Because channelization produces an increase in flow velocity or scour, active bed degradation occurs, causing the movement of substrate particles downstream. As bed degradation continues, degradation of lower streambanks begins, eventually producing bank failure and concave upward banks. During this period of severe instability, the channel is rapidly (in a geologic sense) becoming wider and the water level shallower, sometimes producing a braided flow pattern. Channel widening causes persistent

bank failure in the downstream areas and results in losses of canopy cover and detrital input. These degradation processes move upstream, reducing the rate of channel widening and providing depositional sediment in downstream areas.

Hydrological processes in channelized streams have direct effects on the substrate (embeddedness, scour, and particle size distribution). Transported sediment causes aggradation to occur downstream with deposition on the bed and at the bases of banks. Accretion occurs on the banks with the beginning of the stabilization processes, and seed supplies from riparian vegetation or windblown from other areas settle on these deposits. As vegetation, particularly woody species, becomes established on bank depositional surfaces, stability increases. During this phase of the channel recovery process, meandering features develop through deposition and vegetative stabilization of point bars (inside bend). The return of disturbed stream channels to a dynamically stable, meandering morphology results primarily from the aggradation of banks and beds and the establishment of riparian stands of woody vegetation (Hupp, 1992; Hupp and Simon, 1986, 1991; Simon and Hupp, 1987). Hupp (1992) has estimated that an average of 65 years is needed for this recovery process in non-bedrock controlled, channelized streams in west Tennessee.

A complete concrete lining of natural waterways in western states has long been used to control wet weather flooding. Low flows of reclaimed water are the only source of water for most of the year in these "streams." Wet weather flows are commonly enormous and rapid. Though technically listed as streams and rivers, these engineered channels do not clearly fit definitions commonly understood for either "aquatic habitat" or "streams."

■ **Effects of Flow Regulation.** Many streams are characterized by highly variable and unpredictable flow regimes (Bain et al. 1988). Aquatic macrophyte stands have been shown to be affected by current velocity, but the degree and manner varies with the size of the channel (Chambers et al. 1991). In regulated streams, the importance of a bank-to-midstream habitat orientation becomes magnified. Flow changes displace the shallow shoreline zones, forcing fish restricted to these areas (small fish that use shallow, slow microhabitats) to relocate to maintain their specific set of habitat conditions (Bain et al. 1988). Therefore, if shallow-water habitats are unstable and unable to sustain a well-balanced assemblage, then the functional value of the assemblage is lost and a reduction in organismal population density may follow.

Gislason (1985) illustrates a similar pattern for aquatic insect distribution in fluctuating flows. Bain et al. (1988) also suggest that without the functional availability of shallow, slow, shoreline areas, the stream environment becomes one general type of unstable habitat, dominated by a few habitat generalists and those species using mostly mid-stream habitats. In these cases, the dominance of generalists confounds the assessment of contiguous impact types such as nonpoint source runoff and point source discharges. Comparison of historical and current flow conditions can provide valuable information about the extent to which flow alteration is responsible for degradation in biological integrity.

Comparison of historical and current flow conditions can provide valuable information about the extent to which flow alteration is responsible for degradation in biological integrity.

Alterations to the energy base are not independent of alterations to habitat structure. In many instances, assessment of habitat quality is an assessment of impacts to the energy base.

Energy Source

Stream organisms have evolved to accept and use the energy available to them in natural watersheds. For most small or headwater streams in forested areas of North America, a period of major leaf fall occurs in the autumn. Leaves, in a form referred to as coarse particulate organic matter (CPOM), reach the water and are quickly colonized by bacteria and fungi. The organisms then provide food for invertebrates, which are in turn eaten by fish and other vertebrates. The relative balance of production and respiration varies as a function of stream size, according to the stream continuum hypothesis (Vannote et al. 1980).

Human alteration of the source, type, and quantity of organic material entering streams can affect biological integrity in many ways. Natural shifts in the energy base occur along stream and river gradients, thus providing a major dimension of resource partitioning for the aquatic community. The stream continuum concept (Vannote et al. 1980) outlines different attributes of communities as the energy base shifts from heterotrophic (external) to autotrophic (internal) inputs. These shifts are generally related to increases in drainage area catchments, but exceptions do occur that are related to localized conditions.

Along the stream/river gradient (Fig. 5-6), Cummins (1983) describes the measurement of this shift as a photosynthesis/respiration (P/R) ratio. This P/R ratio is less than 1 in the headwater areas of streams and large rivers. Therefore, these reaches are heterotrophic because in-stream photosynthesis is not a primary energy source. The P/R ratio is greater than 1 in the mid-sized rivers where in-stream photosynthesis is a major contributor to the energy base; the latter are autotrophic. The removal of riparian vegetation for agriculture, channelization, or strip mining, or the shift from natural riparian flora to introduced species for urbanization projects alters the energy base of the aquatic system. Although the stream continuum is thought to no longer hold true for the majority of watersheds, it does exemplify the important considerations in energy base and aquatic ecosystem interaction.

Alterations to the energy base are not independent of alterations to habitat structure. In many instances, assessment of habitat quality is an assessment of impacts to the energy base. However, the evaluation of changes in the energy base can be strengthened by a systematic riparian assessment based on a delineation of natural flora. Alterations in the species of riparian plants influence the functional representation of the aquatic trophic structure biota.

Wilhelm and Ladd (1988) developed a basic tool for conducting natural area assessments in the Chicago region. They presented a checklist of vascular plants of the Chicago region and assigned each species a coefficient of conservatism. This measure expresses the value of the species relative to all other elements in the flora and its particular tie with ancestral vegetation. Low scores are given to native species that are relatively ubiquitous under a broad set of disturbance conditions; high scores are given to species that are sensitive to disturbance; and no scores are assigned to non-native species. In this manner, vegetation can be assessed as representing natural or disturbance conditions.

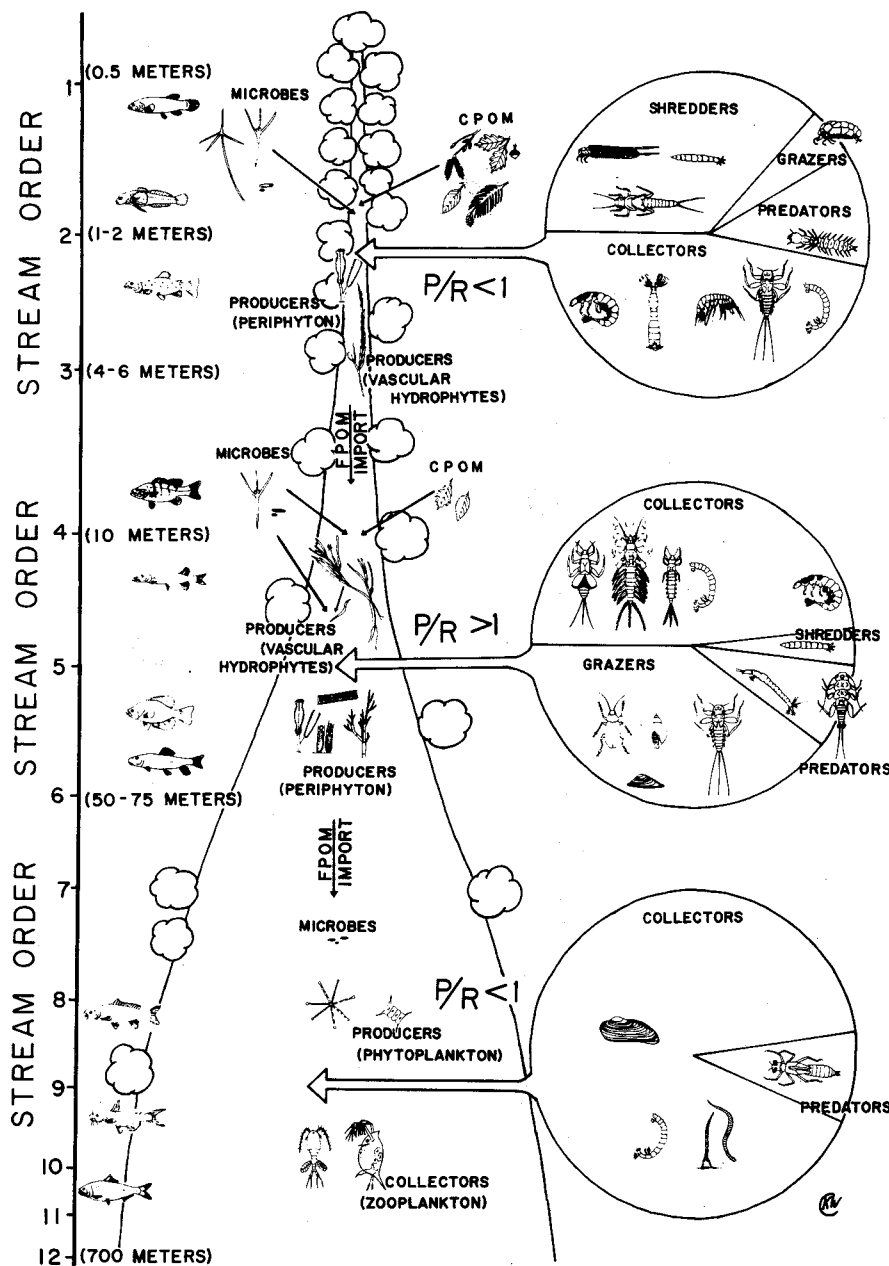


Figure 5-6.—Diagrammatic representation of the stream continuum to illustrate variation in trophic structure of benthic invertebrates (adapted from Cummins, 1983).

Applying this method to riparian corridors would require a similar classification of vegetation. However, much literature is available to aid in classifying riparian flora. The U.S. Forest Service has compiled an extensive database on riparian systems that has been published in several reports (e.g., Platts et al. 1983). Hupp and Simon (1991) recognize early successional species of woody vegetation in riparian zones of disturbed and recovering stream channels in western Tennessee. Padgett et al. (1989) provide a substantial list of references documenting vegetation classification in many of the western states.

Biotic Interactions

Predation, competition, disease, and mutualistic interactions influence where and when species occur within streams. Larval stages of mussels, for example, must attach to the gills of specific fish species to complete their life cycles. Stream communities are often dominated by a few "strongly interacting" species that may have disproportionate effects on the other members of the community (Hart, 1992; Power, 1990). The addition of human influences may alter the integrity of these interactions in ways that alter the abundances of local species and may even cause their demise. Additional human influences are harvests for sport and commercial purposes and the introduction of exotic species, sometimes intentionally but often inadvertently. The practice of stocking fish can be an ecological or genetic disturbance, especially if naturally occurring populations are replaced or infiltrated by stocked individuals. However, the acceptance of this practice is an important societal decision; its advantages and disadvantages must be carefully weighed.

Cumulative Impacts

Even when human actions have an influence on only one of these factors, the effect may cascade through several others. For example, clearing land for agriculture alters the erosion rate and thus the extent to which sedimentation may alter the regional biota. Removal of natural vegetation reduces shading, water infiltration, and groundwater recharge, thereby increasing water temperatures, insolation, and the frequency of flood and drought flows. The resultant agricultural activities may change the stream through channelization, and thus further influence habitat structure. Alterations in the land cover and the channel often have major impacts on water quality (e.g., increased amounts of nitrogen and phosphorus in the runoff from agricultural fields or pesticides in the water). Excess nutrients in modified channels exposed to ample sunlight will enhance the growth of nuisance algae, especially during summer's low flow periods.

Unfortunately, human influences on stream ecosystems cannot be easily categorized (Karr, 1991). The close association between alteration of habitat structure and other impact types complicates the determination of "cause and effect." However, this dimension becomes paramount when mitigative measures are crucial to the attainment of designated uses or biocriteria. In many cases, deductive reasoning, thorough review of the biological data, and use of biological response signatures supported by other environmental data (i.e., physical characterization, toxicity testing, and chemical analyses) aid the assessment of impairment.

The implications of significantly altered systems, for example, channelized streams in urban areas or stream flows regulated by hydroelectric dams, are that reference conditions different from the natural system may have to be established to represent these systems and to evaluate other impact types (Karr and Dionne, 1991). When major impacts (i.e., significant habitat alterations) are present, it is difficult to adequately evaluate changes in community elements and processes that may be attributable to other impacts.

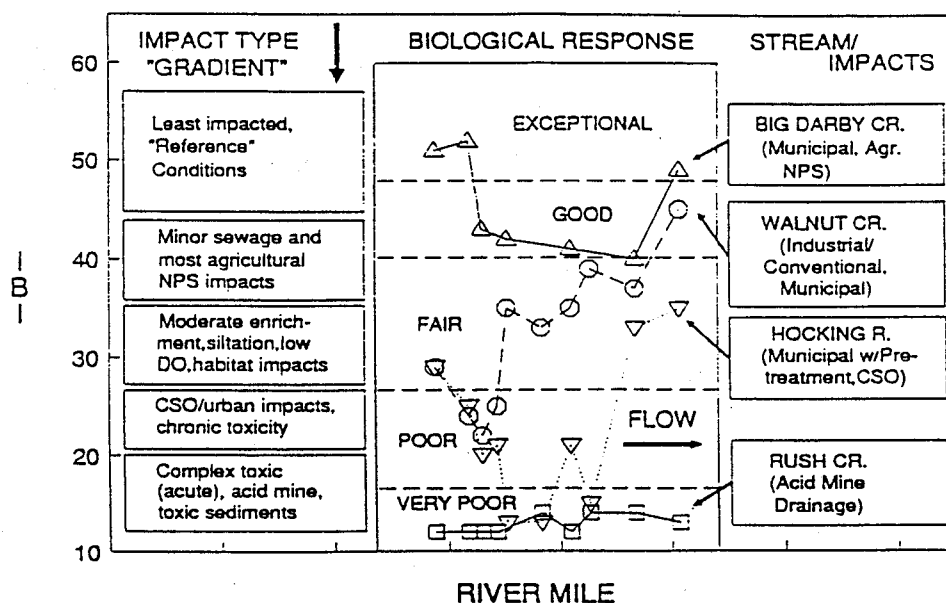


Figure 5-7.—Biological community response as portrayed by the Index of Biotic Integrity (IBI) in four similarly sized Ohio rivers with different types of point and non-point source impacts (Yoder, 1991).

The diversity of influences on the quality of water resources requires the kind of multiple attribute approach common to recent biocriteria program efforts. The use of a multiple attribute approach enables the development of biological response signatures to assess probable "causes and effects."

Using biological response signatures, Ohio EPA (Yoder, 1991) was able to assign each of their more severely degraded situations to one of six groups:

- complex municipal and industrial wastes,
- conventional municipal and industrial wastes,
- combined sewer overflow and urbanization,
- channelization,
- agricultural nonpoint source, or
- other, often complex, impacts.

The Ohio EPA also found that various impact types may have one or two biological response characteristics in common. In rare cases, they have three in common. Therefore, only a multiple assemblage, multimetric approach enables a differentiation among impact types. In certain cases, the severity of the impact is related to the type of impact. The IBI has been used by Ohio EPA to characterize these impact types (Fig. 5-7).

Suggested Readings

Atkinson, S.F. 1985. Habitat-based methods for biological impact assessment. Environ. Prof. 7:265-82.

The diversity of influences on the quality of water resources requires the kind of multiple attribute approach common to recent biocriteria program efforts. The use of a multiple attribute approach enables the development of biological response signatures to assess probable "causes and effects."

- Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69(2):382-92.
- Ball, J. 1982. Stream classification guidelines for Wisconsin. In 1983 Water Quality Standards Handbook. Off. Water Reg. Standards, U.S. Environ. Prot. Agency, Washington, DC.
- Barbour, M.T. and J.B. Stribling. 1991. Use of habitat assessment in evaluating the biological integrity of stream communities. Pages 25-38 in *Biological Criteria: Research and Regulation*. EPA 440/5-91-005. Off. Water, U.S. Environ. Prot. Agency, Washington, DC.
- Karr, J.R. et al. 1986. Assessing Biological Integrity in Running Waters: A Method and Its Rationale. Spec. Publ. 5. Illinois Nat. History Surv., Urbana, IL.
- Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecol. Appl.* 1:66-84.
- Leonard, P.M. and D.J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. *Trans. Am. Fish. Soc.* 115:401-14.
- Ohio Environmental Protection Agency. 1990. The Use of Biocriteria in the Ohio EPA Surface Water Monitoring and Assessment Program. Columbus, OH
- Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for Evaluating Stream, Riparian, and Biotic Conditions. Gen. Tech. Rep. INT-138. Intermountain Res. Sta., Forest Serv., U.S. Dep. Agric., Ogden, UT.
- Steedman, R.J. 1988. Modification and assessment of an index of biotic integrity to quantify stream quality in southern Ontario. *Can. J. Fish. Aquat. Sci.* 45:492-501.
- U.S. Environmental Protection Agency. 1983. Technical Support Manual: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses. Vol. 1-3. Off. Water Reg. Stand., Washington, DC.
- . 1990. *Biological Criteria: National Program Guidance for Surface Waters*. EPA-440/5-90-004. Off. Water, Washington, DC.